# Ontology-based Experimental Support of Conceptual Actions in the Process Production of Aviation Parts Templates

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**Abstract:** The paper presents a set of decisions for improving the processes of designing the template tooling in the aviation industry. Specificity of the offered approach to designing this kind of equipment is to obtaining positive effects of reflecting the life cycle of any template on semantic memory, such as a question-answer. The reflection of the life cycle on the semantic memory makes it possible to develop ontological means of support, to organize structural designing the configured templates of aviation details and also use of means of conceptual experimenting. Such type of experimenting suggests the structure and attributes of the semantic memory cells are focused on the coding of models of questions and answers from the viewpoint of their use in solving the creative tasks. In such modeling, any conceptual experiment is conducted as an automated mental experiment the structure and content of which are operatively used in designing of templates. The ontological support helps to reduce the design complexity, improve the initial design quality, get a shorter pre-production term, as well as to accumulate and transfer the experience of the previously implemented design solutions.

## 1 Introduction

In aircraft manufacturing, template equipment is used for the manufacture, control and assembly of fuselage, wings and aileron parts, including details of their skin, and includes tens of thousands of templates of varying complexity and purpose. Configured templates as specialized equipment for manufacturing and checking of aviation details have a set of features the main of which are the following: complicated geometrical forms, small rigidity, greater scales, and strict requirements to accuracy of manufacturing. In addition, in order to link the details included in each plane section of the aircraft's design, a rigid carrier system is required that fixes the contours of the internal parts that make up this section. So, for example, large parts have to be linked on sheet metal control and contour templates.

The template tooling consisting of tens of thousands of templates is widely adopted in the aircraft construction to produce, check and assemble fuselage, wings, and ailerons, including skin covering parts. Such features of parts determine this fact as the complexity of their geometric shape, low stiffness, large-size dimensions, the strict requirement of production and coupling accuracy. Furthermore, you need to have a system of rigid media fixing inner sides for coupling parts of every aircraft construction plane section where these parts are present.

In general case, a template is not only the carrier of the part geometry and shape, but it also consists of design and engineering data, inner part profiles and axes which are present in this section,

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different design, and engineering holes. In addition, the templates have different information put on them: template name, drawing code and number, make and thickness of the material, fold line and bevel, hole profiles, hole labeling, etc.

In the general case of designing metal sheet templates, you need to be creative to solve tasks of engineering configuration taking into account engineering conditions to employ templates in production, checking and assembling aircraft parts. For these reasons, any geometry of a configured template is more complex than the geometry of a part developed to work with it.

The interconnected complication of the structure leads to the appearance of a set of points on the life cycle in which to make conceptual actions (in Figure 1). At these points, it is impossible to exclude the operations of checking, correcting and repeating the actions, that is, there is a prolonged experimentation.

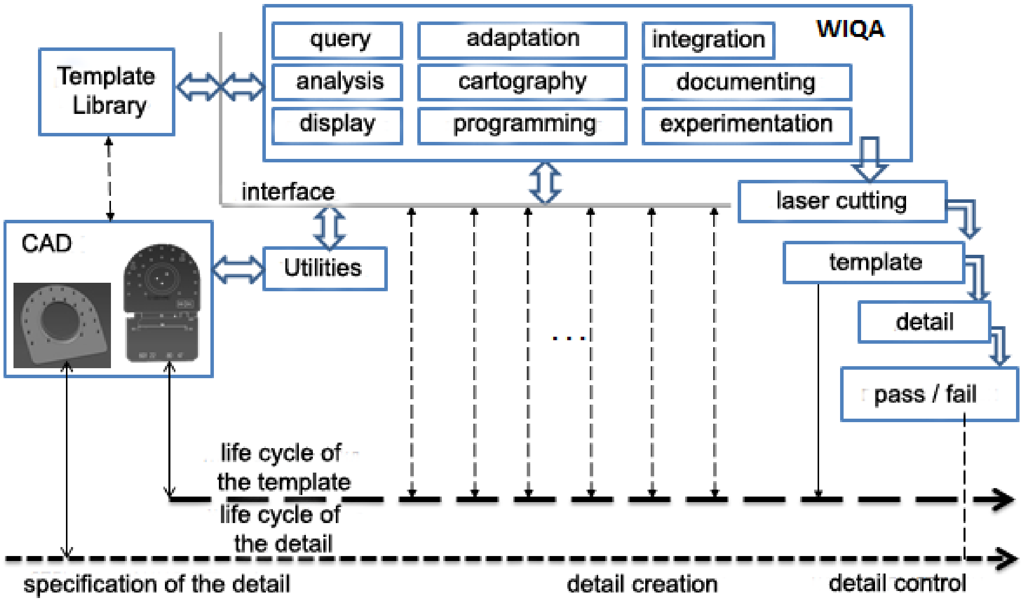


**Figure 1.**The life cycle of the configurable template

Figure 1 highlights an area responsible for the reuse of the template design experience. In the suggested approach, the experience is represented as an «Ontology» component of the toolset within the framework of which the template model library is used.

Even in cases where the best sample library with «rational» nature proven in large-lot aircraft production is employed to design templates, you anyway need to re-create the template tooling when launching new aircraft production, certainly, using mastered templates, improving them and developing the new ones. It means that the creative nature of template design and interconnection remains.

It is reasonable, in this connection, to include experiments (not with templates, but with their models) into the life cycle design of the template (most complex and requiring configuration).

The article suggests including ontological support means to the tool-and-engineering maintenance in design processes of templates. It will ensure the controllable accumulation of template development experience in the form of precedent models ready for the reuse; systematization of template models based on the interactive classification and coupling using ontological systematization principles, controllable use of vocabulary, including concepts, in documents that are developed during work performance. The important special feature of the suggested means is that they rely on the experimental results of semantic models of the template and CNC software models used in the production of templates. Templates are implemented based on the precedent model [1]. The content of the article concerns notably this component and its use in a template design process.

## 2 Methods and Instrument of templates support design

The authors use the mapping of aircraft parts with semantic memory (Figure 2 outlines this memory), to create a library of experience and to conduct conceptual experiments. The means and specifics of the conceptual design, oriented to its mapping to the semantic memory of the WIQA toolkit, are detailed in the publications [2-4]. Features of the semantic memory of the WIQA toolkit is the structure and content of the memory cell, which is focused on loading question-and-answer units (question or answer or their composition).

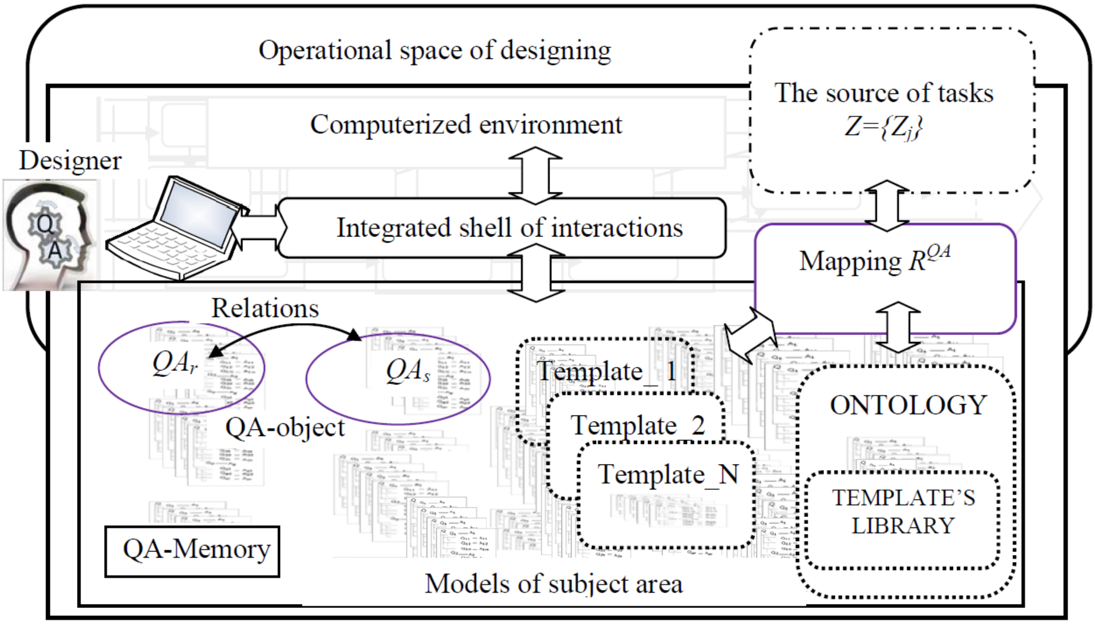


**Figure 2.**Process of Mapping to QA-Memory

But especially important for QA-memory is that it is defined by the expandable (if necessary) pseudo-code programming language LWIQA. The programs in this language can be executed with the help of the interpreter, the interpreter with the compilation of the selected groups of operators and the compiler, and the designer in this performance acts as an «intelligent processor» [3] interacting with the processor of the computer.

For ontological support of the process, the template model in memory is conveniently represented as a precedent. Such a view accumulates and integrates everything that should be useful for the re-use of such a model.

Moreover, during the creation of each template, it must copy not only the geometrical forms of the corresponding detail but also all necessary elements of utility must be included in the template. Such additional components of the templates are oriented on conditions of their use, for example, in assembly operations with other details. The necessity to take into account the different points of view on a template leads to creative tasks, which are better solved during preliminary experiments (before manufacturing a template) with models of their decisions.

Notice that it includes process results and outlines task names in the life cycle diagram the content of which is specified in detail in source [1,5-7]. Authors draw your attention that the design activities required to optimize the suggested life cycle shall comply with standard. The only difference is that the design activity is guided by a (pseudo-code) program within WIQA environment, at this, mappings of a part and the template original are the inputs to perform actions directly within the modeling environment.

To represent every template, we have selected a model M(Zj) for a task Zj of its reuse by the designer found himself in a particular task situation. The first reaction of any person being in a task situation is to «draw himself on the experience and find a suitable precedent for it» [7].

Regardless the fact that precedents are various by their structure and contents, the precedent template has similar logic of access that in common case leads to a precedent logical model $P^L$. The model is linked to the precedent (template) construction life cycle, as well as to its mastering during which the following models are created:

- Text model $\mathbf{P^T}$ representing task setting Z (P_i) which solution leads to the creation of a precedent (template) sample as a result of intellectual mastering of the real precedent. Let us give an example: model $\mathbf{P^T}$ can be represented as a query for template design where basic initial data is: «design a template for cutting and tooling on Z-profile with three legs and holes HO and CO, without undercutting and taking into account an additional material».
- Logical model $\mathbf{P^L}$ instantiating models in the form of an equation for predicate logics recorded in the task setting language $\mathbf{P^T}$.
- Let us examine the above-described model $\mathbf{P^T}$ in the form of predicate logic. Here, the task Z ($P_i$) has the following format including a set of activities as follows:

$$Z\,(P_i) = P^{RabK} \cup P^{Dob} \cup P^{Risk} \cup P^{Otv} \cup P^{Inf} \cup P^{DopE}, \quad (1)$$

where,
$P^{RabK}$ –working profile including:

$$P^{RabK} = P^{Plk1} \cup P^{Plk2} \cup P^{Plk3} \cup P^{Plk3} \cup P^{OtvSO} \cup P^{OtvNO} \cup P^{RiskDet} \cup P^{InfSO}, \quad (2)$$

where,
$P^{Plk1}$ – designing of the 1st leg;
$P^{Plk2}$ – designing of the 2nd leg;
$P^{Plk3}$ – designing of the 3rd leg;
...

- Precedent (template) graphical model $\mathbf{P^G}$, that outlines the precedent (template) using different means.
- QA precedent model $\mathbf{P^{QA}}$ corresponding to task Z ($P_i$).

Let us consider an example of a QA model taking into account the developed classification of the above described «template for cutting and tooling» design for task Z ($P_i$).

Let us determine a list questions and answers:

Q1. What template do we need?
A1. Template for cutting and tooling.
Q2. Is the template single-piece?
A2. Yes //depends on part dimensions.
Q3. What profile to design on?
A3. Z-profile.
......
Q14. Do I need information on CO?
A14. Yes

- Model $P^I$ representing a behavior included in the template (precedent) in the form of the source code.
- Model $P^E$ derived on the executable code and implementing template (precedent) sample.

Note that the special-purpose model $P^I$ allows its representation as the source code of that programming language which is used when developing software for UG NX. But, to extend functionalities of reuse of $P^I$-type models, it is rational to use pseudo-code language LWIQA.

Precedent-oriented on the design of template equipment ontology model with an extended structure of sections, which include sections that additionally provide effective ontological support in solving problems of pattern search, as well as manufacture, control and alignment of the components of the airframe powerplant set.

Let's consider the technological methods and structural interrelationships of the construction of the template rigging, and also present the practical implementation of the elements of the ontological support complex for the design of the template tooling.

Authors use of the toolkit WIQA (Working In Questions and Answers) that helps to create the ontology and its use in conceptual experimenting in designing. The WIQA tools have been tailored to the engineering support of the template lifecycle with the extension of the LWIQA language based on the description in the Extended Backus-Naur Form (EBNF) [5].

The choice and implementation of a part of the template structure that supplements the shape (and dimensions) included in the template of a particular airplane.

Designing a template is inherently associated with a tool such as CAD. This process begins after the part specifications have found their geometric representation in the CAD system.

Presently, the considered subject (template tooling) is fully modelled within UG NX system in a so-called «manual» mode which increases its labor intensiveness and error number, extend the time for engineering preproduction as a whole.

Construction of a mathematical model for the template tooling comes down to profile modeling. Figure 3 shows a common modelling diagram. All types of template tooling are modeled based on the given diagram.

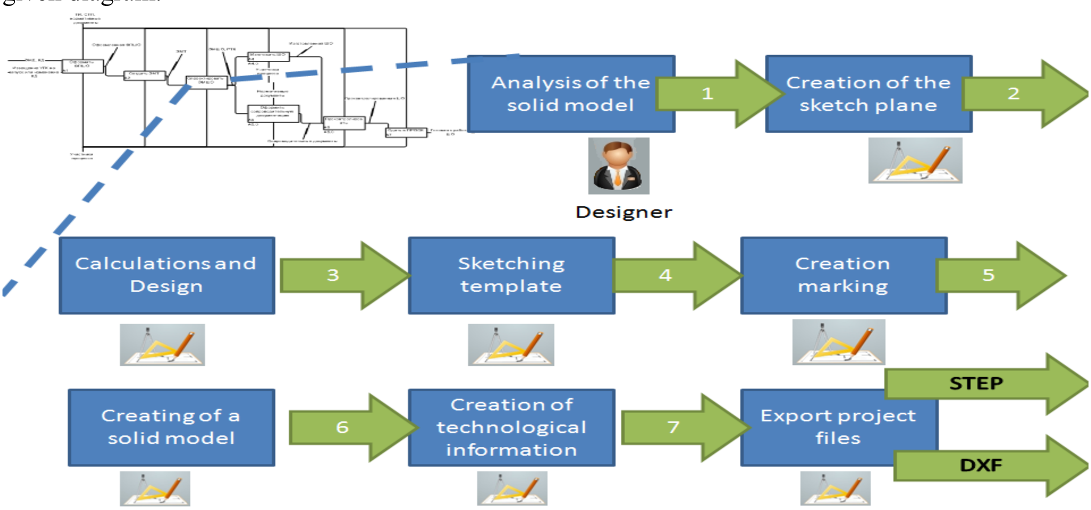


**Figure 3.** E-Model of Template Tooling Design Process

The diagram shows the following main stages of creating a mathematical model of the template: Analysis of the geometry of EMD.The stage of theoretical comprehension of the future appearance of the template, as well as the choice of the optimal location of the part in the modeling space for the further convenience of designing the mathematical model of the tooling.

Construction of the sketch plane. The template sketch plane is the first item in the design of the template. As a rule, it is built on a flat or non-working surface of the EMD.
Performing the necessary design and planning operations. Number and types of design and design operations, as well as their options, depending on the features of the equipment and experience of the designer.

Design a sketch template. The sketch is created on the plane, and based on the geometry of the part, the complexity and number of operations performed during its design can vary greatly.

Construction of marks. The number and types of required marks directly depend on the type and group-sets of templates. However, in any type of template, there will be at least one mark - this is the mark of the contour of the trimmed part. All marks of the contour in the production of the template are performed by laser engraving, and therefore they are placed on a separate modeling part layer.

When the template snap-in is fully ready, and the contour is closed, the "Extruding" operation creates a solid pattern model. Its main purpose is to link the equipment and control of the manufactured rig to the Control measuring machine (CMM).

Marking technological information on the model of the template. All technological information is applied to the solid body of the template and placed on the modeling reference layer.
Creation output files. With the finished electronic template model, two output files are generated:

- File DXF - serving for cutting a template from a metal sheet with a laser.
- STEP file - for monitoring the contour of the manufactured template on the CMM.

The information about the part includes the geometry plane of the part for which the template is designed. This geometry element is transferred into the WIQA tool-modeling environment with the help of a special utility to display details on the semantic memory of this system. The second purpose of these actions is to analyse this information and to form a query to the library of templates.

All these actions and subsequent (in the course of the life cycle of the template) are performed under the control of the (pseudo-code) program, in the WIQA environment, where the parts mapping and the original version of the template serve as input data for performing actions directly in the modeling environment.

The analysis of the UG NX system and the modeling environment of WIQA allows concluding that the data of the system for a sufficient number of possibilities for creating on their basis a set of ontological support for the process of designing the template rigging.

## 3 Ontological support for the process of designing aviation template

The central part of tooling design ontology or any other ontology generated in WIQA environment is taken by «Vocabulary». The vocabulary structure has a section for presenting the basic types of templates based on the use of the model templates described above. The vocabulary functions not only contain template definitions but also search keys that allow you to search based on special queries. The WIQA environment is aimed at conceptual modeling [6] based on the pseudo-code programming of designers» activity [7]. It also concerns the routing of accessing the ontology components, including accessing references to the conceptual template models.

The WIQA toolset makes it possible to use the requisite tooling in the vocabulary ontology. With the template, you can create links to formalize templates based on attributes: «whole and parts» because it consists of elements defining the template; «Inheritance», because in most cases the template has a parent or an ancestor. After that, the attributes are populated.

Note that you can both assign names to relations to derive their semantics and comment them. This option is useful for pragmatic relations, for example, for the tool-type ones (linking the template with the tools for its processing or mechanical processing).

Thus, the stage of ontological modeling of precedents of templates is added to the existing life cycle of designing and manufacturing the tooling. At the same time, it should be noted that such modernization was possible due to the formalization of the ontology model and the separation of the main dictionaries of terms:

- template accessories;
- manufacture;
- control;
- regulatory and technological support.

These terms groups reflect all the production elements involved in the development and creation of a template snap. At the same time, to ensure the flexibility of the production system to changing conditions, the designed ontology is open and extensible in order to fully meet the requirements of aviation production.

Objects of template classes in the interactive classification are defined and investigated with reference to the technological production processes. Each of these objects has its own constructive components that allow the most rational determination of the ratio of the template to the manufactured part. These features of the template structure are realized as an ontology section and as a formal representation of the classifier tree.

The method of ontological support of the design of the template tooling takes into account the controlled accumulation of the experience of template development in the form of use case models prepared for reuse. The algorithms for designing the template equipment are integrated into the technological preparation of production and are characterized by an increased degree of automation of the design process achieved by programming part of the designer's typical operations in terms of the design of the geometry of the electronic template model.

Positive effects from the inclusion in the instrumental and technological support of the design of aircraft templates means of ontological support:

Controlled accumulation of experience in the development of templates in the form of use case models prepared for reuse.

Systematization of template models, based on interactive classification and binding using the mechanisms of systematization in ontologies.

Controlled use of vocabulary, including concepts, in documents developed in the course of work.

Creation of precedent models is carried out within the framework of the WIQA question-and-answer environment, which allows using a set of tools by all participants in the life cycle of designing and manufacturing the template rigging. Also, an extensive toolkit of WIQA capabilities allowed implementing an interactive classifier that helps to increase the rationality of the «detail-rigging» relationship.

An important feature of the proposed tools is that they rely on the results of experiments that are conducted with semantic models of templates and models of numerical control programs that are used in their production.

## 4 Conceptual experimentation based on the display of the template on the question-answer memory

The selection and implementation of that part of the template structure that complements the form (and dimensions) of the specific section of the part included in the template are derived for some design tasks that allow for alternative solutions. Even in cases where the library of their «best designs» was used to design the templates, which confirmed their «rationality» in the production of already known types of aircraft, in the transition to the production of a new aircraft, the adaptive design to create a new, of course, using the mastered templates, and developing new templates. That is, the creative nature of designing templates and their interconnection will remain. That is why the state of affairs and determining the appropriateness of including experiments in the life cycle of design (especially complex, configurable) templates.

At the initial stages of the design of templates, the use of conceptual experimentation is used to develop selected options for engineering solutions and obtaining new ones by conducting conceptual experimentation [5].

A conceptual experiment is a mental experiment, content, and process that quickly maps to the semantic memory, and also analyzes the results during the experimentation with useful goals.

The mapping of the design process to the question-answer memory allows for conceptual experimentation, which implies the possibility of stopping at any stage of the design, evaluating the decision taken, multiple visualizations and the possibility of correction. For the above algorithmic scheme, it is important to experiment with the template developer for the task chosen by him (not only related to laser cutting procedures). In the article for conducting such experiments a number of tools are presented, including tools for registering template models in the library and tools for dynamic visualization of laser cutting processes in time.

The basic possibilities of conceptual experimentation are based on the «cartographic» representation of aviation patterns. A cartographic model providing layer-by-layer structuring for the specialization of work for each layer (see Figure 4) represents configurable templates, carrying information about their geometry and a set of technological information, broadcasted to the program for their production. In general, the template, not only is the carrier of the geometry and shape of the part but also includes the structural and technological bases, contours and axes of internal parts that fall into this section, various structural and technological holes. In addition, various information is put on the templates: the name of the template, the cipher and the drawing number of the product, the brand and thickness of the material, the directions of the fold lines and the bead mills, the outline of the relief holes, the marking of the holes and other information.

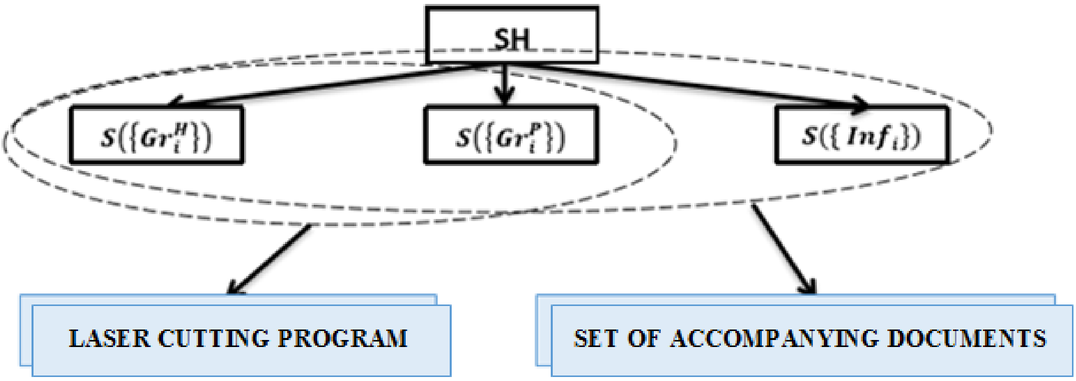


**Figure 4.**Application of cartographic layers in the design of templates

In addition to layering to form documentation and form elements of a laser processing program, this method allows you to divide the elements into the states that are accessed. Reducing the number of structural elements, allows you to solve the task without losing attention [8].

The set of techniques for conceptual experimentation with dynamics (design procedures) and the statics (state) of the life cycle of configurable templates, the study of which is carried out in the semantic question-answer memory and leads to an increase in the degree of automation of the design process and the quality of its result.

The conceptual experimentation technique presented in the form of pseudo-code programs, the execution of which can be performed in a step-by-step mode, with interrupts on any of the operators for performing experimental actions and procedures, if the template maker needs this.

In working with pseudo-code analogs of numerical control commands for laser cutting, two interpretations are supported, one of which is used to simulate cutting in the field of a specialized graphical editor of the WIQA tool. And the second interpretation allows switching from a pseudo-code program simulating a certain cutting to its version in working G-codes with instructions for preparation for cutting and operational interaction with laser equipment.

The second view is used not only to adapt the programs for manufacturing a template for equipment of different manufacturers but also can serve as the basis for optimizing the laser cutting process.

To minimize idling, it is necessary to maximize the unification of disparate elements in associated closed or open contours. The second aspect to minimize idling is the optimal determination of the insertion points in the contours so that the sum of the distances between the insertion points is minimal. Providing the designer of the templates with the possibility of experimenting with laser beam entry points in the processed contours, as well as dynamically visualizing the cutting in time, with the possibility of correcting these points, makes it possible to rationalize the movements of the head of the machine at idle. Thus, the purpose of experimentation is to reduce the time of making a template from a sheet by reducing idling (see Figure 5).

The progress of the experiment:

The template designer loads the prepared template model to form the control program.

Specify the starting point for processing, for example, the initial position of the carriage of the laser emitter in the machine.

A rational way of traversing the component contours is calculated programmatically, with the output of the basic metrics, such as the useful path and idling.

By a visual presentation, the designer decides whether to correct the calculation results and, if necessary, moves the start point or the cut-in points along the contours and causes a recalculation of the processing metrics until it receives the results satisfying it.

Based on the results of the experimental finding of contour traversing points, a machining program is developed for the CNC machine.

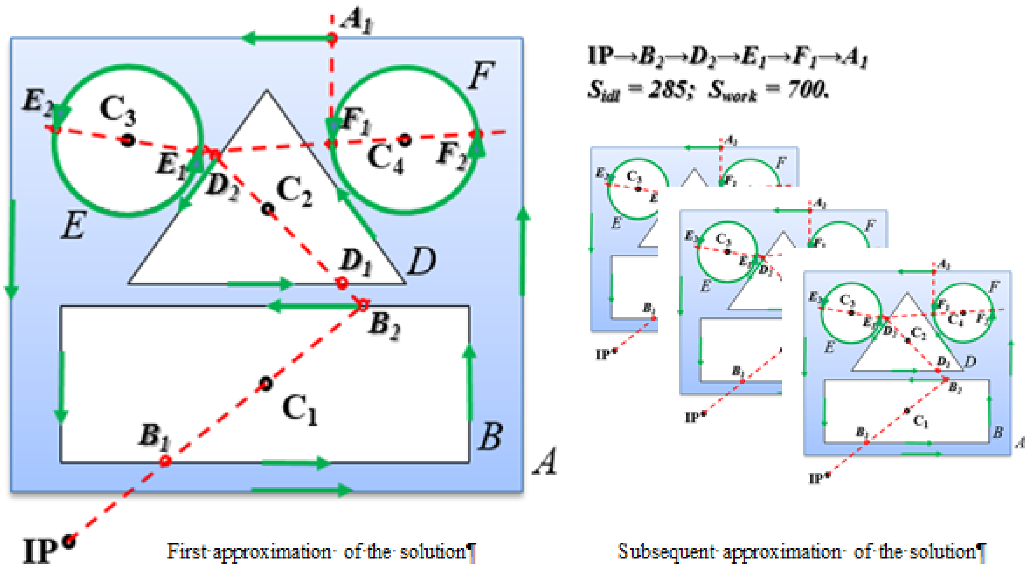


**Figure 5.**Step-by-step optimization of the path of the laser beam

Lastly, the external contour of the template is cut out, to determine the insertion point in which the nearest point of the outer contour from the insertion point to the last internal element is located. The point A1 on which the previous template was cut on the sheet plays the role of the starting point when calculating the traversal path for the next template.

To reduce the negative impact, it is necessary to purposefully reduce the reasons for deviating from the right decisions. The main purpose of experimentation is to identify random errors and defects caused by the actions of designers. The presence of errors is detected as a deviation of the result from the requirements in the process of verifying the materialization of the solution. All such anomalies are discovered during the life cycle of the template and significantly affect the result of the design process. Introduction of the mechanism of layers makes it easier to work on designing templates since each layer consists of fewer elements and carries logical completeness, which allows you to operate with fewer components. In addition, the design process from parallel to serial is converted, which also reduces its complexity. Reducing the number of deviations is also facilitated by a formalized approach to defining tasks and responsibilities within the organization.

The final step in the use of the WIQA system in the life cycle of the template is the design of the accompanying documentation. Documentation is one of the basic functionality of the WIQA toolkit, for the implementation of which any, also the document forms are mapped to semantic memory, with display units available for use in pseudo-code programming. So any result of experimentation, if it turned out to be working and embedded in the template project, can be quickly transferred to the appropriate document forms.

Operational documentation in the WIQA environment is transferred to QA-memory, and for each sample document, a question-answer presentation of its structure and a template for visual presentation of the document on the sample of its hard copy are formed.

The diagram on the previous figure reflects the fact that during the design of the template, it is required to generate certain normative documentation, which includes a map showing both the geometry of the designed template, the application variant (the sketch of the template application for the part), and the accompanying information to be entered into certain cells of a table document.

## 5 Conclusion

The practical value of the described work is a set of developed software on the basis of CAD NX 7.5 and the question-answer environment WIQA.NET providing an increase in the degree of automation of the process of designing leaf patterns due to:

- experimentation capabilities that allow you to adapt the models stored in the library and choose the best solutions already in existing solutions;
- libraries of typical configurable templates, including their semantic representations, and information about the production of templates and their use in forms that provide prompt access to semantic requests, as well as facilitating their reuse.
- formalization of the accumulated design experience, simplifying both the work of specialists with little experience, and relieving repetition of monotonous operations for more experienced ones.

Analysis of the results of experiments allows us to speak about the effectiveness of the proposed solution, since the complexity of designing the template equipment has decreased by an average of 20%, and the metal capacity of manufacturing - by 25%, in some cases - by 100%. The search relevance factor for the template snap varies from 0.6 to 0.85, which is a good indicator.

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